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The Content of Heavy Metals in Soils and Leaves of Silver Birch Plantations (Moscow)

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Abstract. The ecological condition of urban plantations is an urgent problem of our time. The condition of plantations and soils characterizes the ecological and sanitary condition of the environment. In the structure of the cities, urban and forest parks are of particular importance. They mainly perform recreational functions, contributing to improving the health and well-being of city residents. Woody plants, due to their properties to absorb harmful substances that come with air pollution from industrial enterprises and motor vehicles, are one of the main mechanisms for stabilizing the environmental situation in cities. Technogenic pollutants, a significant proportion of which are heavy metals, make a significant contribution to the pollution of ecosystems. Heavy metals represent a specific category of particularly toxic pollutants. The main sources of their entry into the soil are related to human activity. Heavy metals are accumulated by plants, which negatively affects the condition of urban plantations. Soil contamination with heavy metals leads to significant changes in the agrochemical state of the soil and the entire ecosystem. The accumulation of heavy metals in ecosystems depends on various factors, mainly on the condition of the soil and vegetation and the level of anthropogenic impact. The article describes the quantitative content of copper, lead, cadmium, nickel and zinc in the samples of soil and leaves of silver birch growing in the territories of Moscow parks. The sample plots have been laid in different functional areas of the parks: at the alleged sources of negative impact, as well as at points farthest from anthropogenic objects. The results of the study have been compared with the standards for maximum permissible concentrations, the biological absorption coefficient has been calculated, and the accumulation of heavy metals has been revealed depending on the location of the object relative to potential sources of pollution. The soils of the plantations under study contain concentrations of heavy metals that do not exceed the MPC level. The exception is zinc. Its amount in some sample plots has been increased several times. Birch leaves have shown an uneven accumulation of heavy metals depending on both the concentrations of the elements in the soil and the location of the sample plots.

Keywords: birch, silver birch, heavy metals, environmental pollution, soil, leaves, biological absorption coefficient, Moscow parks

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Научная статья

Содержание тяжелых металлов в почвах и листьях насаждений березы повислой (Москва)

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Аннотация. Экологическое состояние городских насаждений является актуальной проблемой современности. Оно характеризует и состояние окружающей среды в целом. В структуре городов особое значение имеют городские парки и лесопарки, которые выполняют преимущественно рекреационные функции, способствуя улучшению здоровья и благополучию горожан. Посадка древесных растений, поглощающих вредные вещества, поступающие с воздухом, загрязненным промышленными предприятиями и автотранспортом, – один из основных механизмов стабилизации экологической ситуации в городах. Значительный вклад в загрязнение экосистем вносят техногенные поллютанты, весомую долю которых составляют тяжелые металлы. Тяжелые металлы входят в категорию особо токсичных загрязнителей. Основные источники их попадания в почву связаны с деятельностью человека. Тяжелые металлы накапливаются растениями, что отрицательно сказывается на состоянии городских насаждений. Загрязнение почвы тяжелыми металлами приводит к серьезным изменениям в агрохимическом состоянии почвы и во всей экосистеме. Накопление тяжелых металлов в экосистемах зависит от различных факторов, преимущественно от состояния почвы, растительности и уровня антропогенного воздействия. В статье описано количественное содержание меди, свинца, кадмия, никеля и цинка в образцах почвы из парков Москвы и листьев березы повислой, произрастающей на территориях этих парков. Пробные площади заложены в разных функциональных зонах парков: у предполагаемых источников негативного воздействия, а также в точках, наиболее удаленных от антропогенных объектов. Полученные данные сопоставлены с предельно допустимыми концентрациями, рассчитан коэффициент биологического поглощения, выявлено аккумулятивное накопление тяжелых металлов в зависимости от расположения объекта относительно потенциальных источников загрязнения. Концентрации тяжелых металлов в почвах исследуемых насаждений не превышают предельно допустимый уровень. Исключением является цинк, его количество на некоторых пробных площадях было повышено в несколько раз. Листья березы показали неравномерное накопление тяжелых металлов в зависимости как от концентраций элементов в почве, так и от расположения пробных площадей.

Ключевые слова: береза, береза повислая, тяжелые металлы, загрязнение окружающей среды, почва, листья, коэффициент биологического поглощения, парки Москвы

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Introduction

Currently, the environmental situation in the urban environment of Moscow is an urgent problem, especially taking into account the active urban planning policy. Moscow is one of the most actively developing megapolises; the city's road network and rail transport are developing at a rapid pace and manufacturing enterprises are operating, which in turn affects the city's ecosystem. Environmental monitoring of urban plantations is an important basis for analyzing the conditions of urban areas and further planning corrective actions. Plants, being sensitive biological objects, accumulate pollutants. Heavy metals represent a significant proportion of anthropogenic pollutants [3]. In this regard, there is a need to study the accumulation of heavy metals by plants growing in urban plantations. Of great importance for the ecological state of Moscow are the Losiny Ostrov National Park (hereinafter – the Losiny Ostrov), which occupies a large area and is surrounded by man-made features, the N.V. Tsitsin Main Botanical Garden of the Russian Academy of Sciences (hereinafter – the MBG), the Kolomenskoye Museum-Reserve (hereinafter – Kolomenskoye), which are recreational facilities popular with citizens, therefore it is advisable to study the influence of man-made chemical elements on them. Silver birch *Betula pendula* Roth. (hereinafter – birch) has been chosen for the research as a species ubiquitous in Moscow plantations, exhibits resistance to negative environmental factors, and has a high dust- and gas-trapping capacity [17].

The aim of the research has been to study the content of heavy metals in the soil and silver birch leaves in the territories of the Losiny Ostrov, the MBG and Kolomenskoye.

Research Objects and Methods

To determine the content of heavy metals in the Losiny Ostrov, sample areas have been laid on 4 permanent sample plots (hereinafter – PSPs 1, 2, 3 and 4). The choice of sampling points is determined by the functional zoning of the territory, anthropogenic load, as well as the expected influence of technogenic facilities.

PSP 1 is located in a recreational area within the city and is adjacent to the highway. PSP 2 is a recreational area and the most visited peripheral part of the national park. PSP 3 is a recreational area bordering the Moscow Automobile Ring Road. PSP 4 is a protected area, located in the regional part of the national park. Therefore, the distribution of heavy metals at sampling points located in protected and recreational areas, as well as in close proximity to highways, is given depending on the location of the sample plots.

On the territory of Kolomenskoye, samples have been taken at the following sample areas: from the Moscow Polymetal Plant Side (PSP 5), from Prospekt Andropova side (PSP 6), at the intersection of Prospekt Andropova and Kashirskoye Highway (PSP 7) and in the center of the park (PSP 8). Thus, the territories with strong and weak anthropogenic impact have been surveyed.

In the MBG, samples have been taken from 3 points, – in the arboretum (PSP 9), in a natural forest area (PSP 10) and from an area adjacent to the territory of VDNKh (the Exhibition of Achievements of National Economy) (PSP 11). Such an arrangement of material collection points made it possible to estimate the load on the MBG in different functional areas and with different recreational loads.

Each sample group of plant sample (leaves) for each species under study has been made point by point and has included 50–100 leaves selected from 5–10 individual trees. The material has been collected after the leaf growth has stopped. The leaf blades have been collected from the lower part of the tree crown from the maximum number of available branches evenly around the tree. The leaves have been picked only from the shortened shoots [20]. Along with the collection of plant material, soil samples have been taken in accordance with GOST R 58595–2019 “Soils. Sampling”. The soil samples have been taken at the tree growing points using a reed soil auger, providing a sampling depth of at least 25 cm for an individual sample.

Agrochemical analyzes have been carried out at an accredited test laboratory of the Federal State Budgetary Institution State Center for Automatic State Center for Agrochemical Service “Moskovsky”.

The leaf samples have been tested for the content of heavy metals (copper, lead, cadmium, nickel and zinc). The soil has been tested for the basic agrochemical indicators (pH, hydrolytic acidity, phosphorus, potassium, ammonium nitrogen, organic matter) and heavy metals.

The soil pH has been determined in a salt extract of 1n. KCl in compliance with GOST 26483–85 “Soils. Preparation of Salt Extract and Determination of its pH by CINAO Method”; the soil hydrolytic acidity has been determined using Kappen method in compliance with GOST 26212–91 “Determination of Hydrolytic Acidity by Kappen Method Modified by CINAO”. The measurements have been carried out on a Seven Compact S220 pH meter/ionomer.

The determination of mobile phosphorus and potassium compounds by Kirsanov method modified by CINAO (GOST R 54650–2011) has been carried out using the KFK-3-01-ZOMZ spectrophotometer and the AAS-30 atomic absorption spectrophotometer.

The analysis of the quantitative content of ammonium nitrogen in the soil has been carried out using the photometric method according to GOST 26489–85 “Soils. Determination of Exchangeable Ammonium by CINAO Method” using the KFK-3-01-ZOMZ spectrophotometer.

The content of organic matter in the soil has been determined by Tyurin method according to GOST 26213–91 “Soils. Methods for Determination of Organic Matter” using the KFK-3-01-ZOMZ spectrophotometer.

To determine the content of heavy metals, dry ashing of leaf samples has been carried out in a muffle furnace with a stepwise temperature increase to 450 °C. Then the ash has been dissolved with a mixture of 10 % hydrochloric and 5 % nitric acids, transferred into 50 ml test tubes and brought to the mark with bidistilled water. The extracts obtained from the leaves have been analyzed on the “Shimadzu” AA-7000 atomic absorption spectrophotometer in accordance with the Guidelines for the Determination of Heavy Metals in Soils of Farmland and Crop Products [9]. Soil samples have been analyzed for heavy metals in accordance with ERD F 16.1:2.2:2.3:3.36–2002 “The Measurement Methodology of Gross Content of Cadmium, Cobalt, Manganese, Copper, Nickel, Lead, Chromium and Zinc in Soils, Sediments, Sewage Sludge and Waste by the Method of Flame Atomic Absorption Spectrometry”.

All the analyzes have been carried out in triplicate, and the results have been statistically processed using the analysis package in MS Excel.

The data obtained as a result of analyzes of soil concentrations has been compared with the value of the maximum permissible concentration (hereinafter – MPC) of gross forms [14]. For plants, MPCs according to Prochorova [19] have been applied. The calculation of the biological absorption coefficient (hereinafter – BAC), which is the ratio of the content of an element in a plant to the content of an element in the soil, has also been carried out [11]. With the BAC value has been about one and above, the plant has been considered as an element concentrator; if the value has been an order of magnitude higher, it has been considered a superconcentrator.

The method of statistical data processing [7] has been used in the work.

Results and Discussion

In order to study the general agrochemical state of soil conditions (basic soil indicators) of the objects of study, an analysis of agropedological conditions has been carried out first, the results of which are shown in the table below.

Due to the large volume of research, the experimental data have been grouped according to the fundamentals of statistical theory. Indicators that are close in value have been integrated into different groups.

The Basic Agrochemical Soil Indicators

Object	№ group PSP	pH KCl, units pH	Hydrolytic acidity, mmol/100 g	NH ₄ , mg/kg	P ₂ O ₅ , mg/kg	K ₂ O, mg/kg	Organic matter, %
The Losiny Ostrov	1	4.4±0.2	5.25±0.63	3.2±0.48	31±6	258±39	4.15±0.62
	2	3.9±0.2	7.59±0.91	4.8±0.72	30±6	96±14	6.07±0.61
	3	4.0±0.2	6.97±0.84	8.9±1.34	15±5	76±15	3.15±0.47
	4	5.5±0.2	1.90±0.23	5.9±0.89	15±5	116±17	3.40±0.51
	<i>Mean value</i>	4.5	5.43	5.7	23	137	4.19
The “Kolomenskoye” Museum-Reserve	5	4.4±0.2	3.40±0.41	6.3±0.95	66±13	140±21	2.02±0.40
	6	4.5±0.2	5.25±0.63	6.1±0.92	41±8	112±17	3.01±0.45
	7	4.3±0.2	4.48±0.54	8.3±1.25	96±19	147±22	4.10±0.62
	8	5.7±0.2	2.16±0.26	10.1±1.01	38±8	908±136	3.28±0.49
	<i>Mean value</i>	4.7	3.82	7.7	60	327	3.10
The N.V. Tsitsin Main Botanical Garden	9	5.7±0.2	2.21±0.27	5.9±0.89	139±28	71±14	4.70±0.71
	10	5.7±0.2	1.74±0.21	6.4±0.96	210±42	79±16	2.72±0.54
	11	5.5±0.2	1.98±0.24	6.2±0.93	63±13	125±19	2.56±0.51
	<i>Mean value</i>	5.6	1.98	6.2	137	92	3.33

According to the data in the table, the soil in the Losiny Ostrov is predominantly strongly acid. At PSP 4 it is neutral.

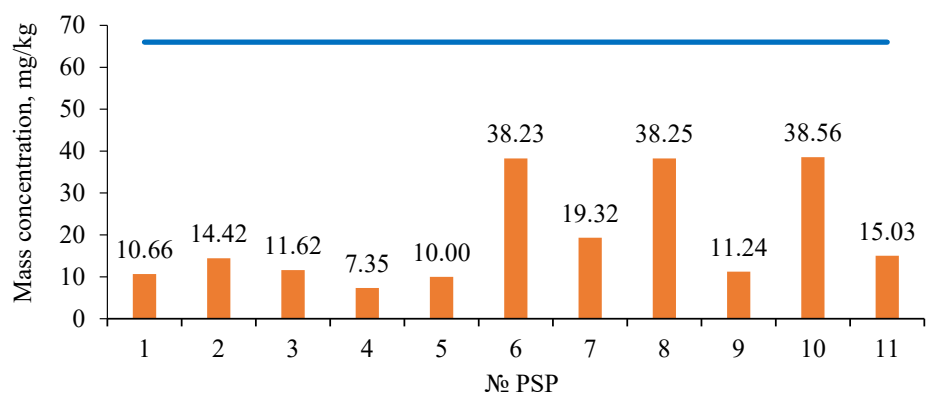
In Kolomenskoye, the soils are strongly and moderately acidic, as well as close to neutral.

In the MBG the soils are close to neutral. The mass fraction of exchangeable ammonium in the studied soils is in the average range for sod-podzolic soils. The provision of soils with mobile phosphorus and exchangeable potassium in the studied sites is extremely uneven [5].

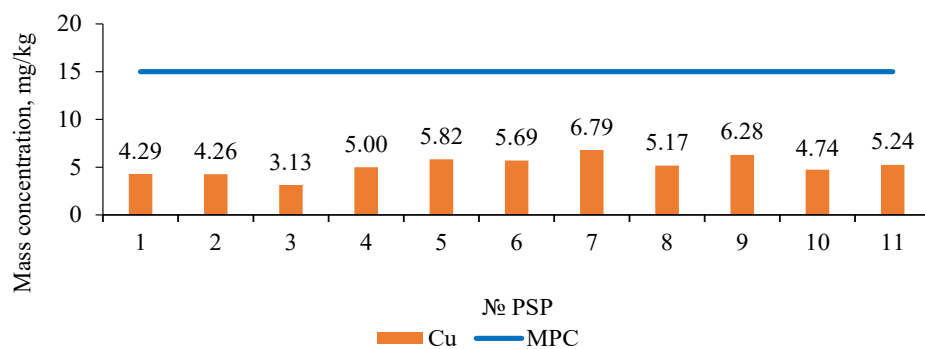
Low phosphorus content has been found in the Losiny Ostrov, medium – in the MBG, low and medium – in Kolomenskoye.

A very high provision of soils with exchangeable potassium has been found in PSP 1 and PSP 8, an increased provision – in PSPs 5, 7 and 11; medium – in PSPs 2, 4, 6 and 10, low content has been recorded in PSPs 3, 9 and 10. According to the content of organic matter in the upper soil horizon, it has been revealed that the studied samples have medium and high humus content.

In the course of the study on the PSPs, data on the content of heavy metals in the soil have also been obtained. However, to calculate the BAC, which characterizes the degree of the element accumulation, it has become necessary to identify heavy metals in birch leaves (Fig. 1–5).



a



b

Fig. 1. The copper content in the soil (*a*) and birch leaves (*b*)

Copper is an important element involved in the plant physiological and biochemical processes. The optimal amount of copper in the soil is considered to be 5–20 mg/kg. A sufficient amount of copper in the soil increases the photosynthesis intensity, promotes plant disease resistance and increases drought and frost resistance. High concentrations of copper are toxic to plants, which manifests itself in the form of slow growth, browning and leaf death. Fig. 1 shows that the mass concentration of copper both in the soil and birch leaves in all the sample plots under study is within the MPC norm. The highest values have been recorded in Kolomenskoye and in the MBG; the lowest copper content in the soil has been recorded in the protected area of the Losiny Ostrov. In all the sample plots, the coefficient of biological absorption of copper is less than 1, which means that birch is not a concentrator of this metal.

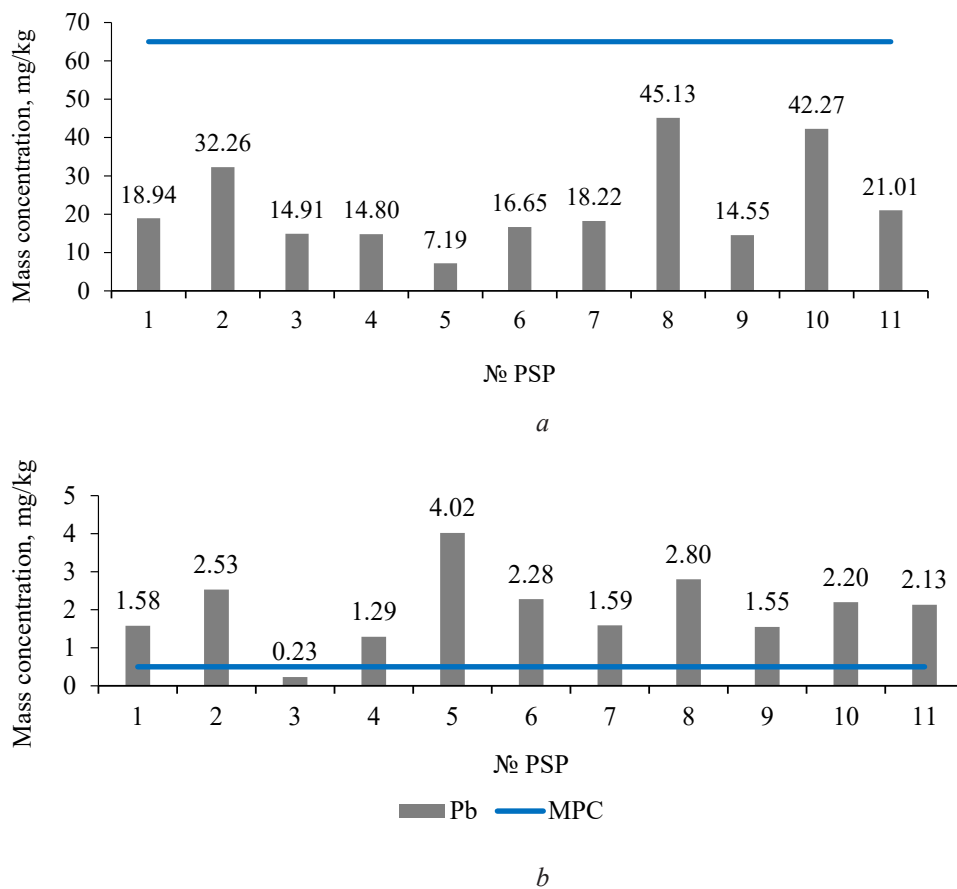


Fig. 2. The lead content in the soil (a) and birch leaves (b)

Lead is a highly toxic heavy metal and belongs to the class of substances highly hazardous to living organism (GOST 17.4.1.02–83 «Nature Protection. Soils. Classification of Chemicals for Pollution Control»). High concentrations of lead in plants are typical for technogenic territories, areas with high anthropogenic load and near industrial enterprises. The increased lead content in plants inhibits photosynthesis and respiration. Visually, an excess of lead is manifested by the intense dark green color of the leaves, their rolling and death. As can be seen in

Fig. 2*a*, the lead content in the studied soil is below the MPC. At the same time, the results obtained for the lead concentration in the leaves (Fig. 2*b*) on all sample plots significantly exceed the inspection standard. An exception is the trial plot located in the recreational area of the Losiny Ostrov. The highest value has been detected in birch leaves in Kolomenskoye at PSP 5; it exceeds the MPC by 8 times. Presumably, such a severe lead contamination can be explained by the close proximity of the sample plot to several technogenic facilities: the Moscow Polymetal Plant, the Research Institute of Chemical Technology, the Dukhov Automatics Research Institute and the Kuryanovsky Sewage Treatment Plant on the opposite bank of the Moscow River.

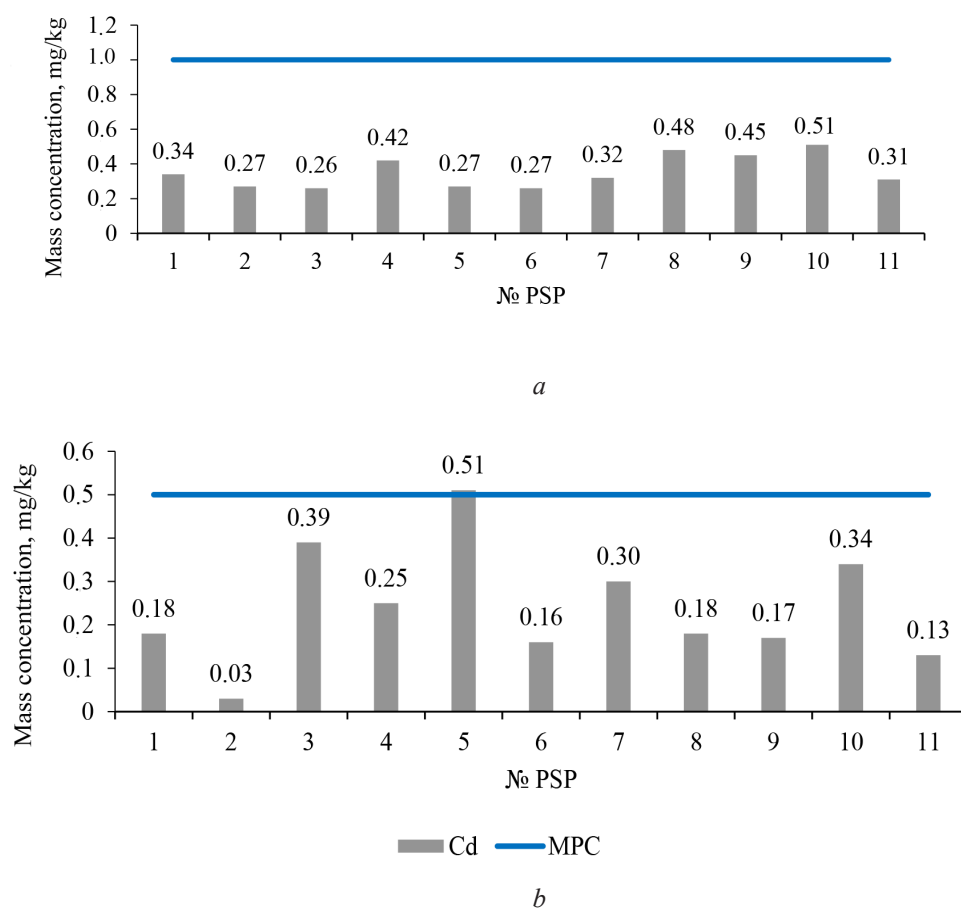


Fig. 3. The cadmium content in the soil (*a*) and birch leaves (*b*)

Cadmium is an element that does not have a positive biological effect on plants; however, there is evidence that it specifically promotes the synthesis of certain amino acids [12]. Cadmium, like lead, is a highly toxic heavy metal; its increased content has negative consequences for plant organisms. This element interferes with normal metabolism, disrupts the processes of carbon dioxide fixation and transpiration, and inhibits photosynthesis. Signs of the cadmium toxic effect are damage to the root system, slowdown in plant growth and development, change in leaf color to red-brown and chlorosis [13]. According to the results of our analyzes (Fig. 3*a*, *b*), cadmium in the soil is within the MPC, its average values are 2–3 times lower than the MPC,

which indicates a slight intake of cadmium into the soil from the atmosphere. In the birch leaves, the value of cadmium concentration at the MPC boundary has been recorded at PSP 5; the reason for accumulation, in our opinion, is the cluster of technogenic facilities near this sample plot. The BAC value at PSP 7 is 0.94, which indicates the concentration of cadmium by birch.

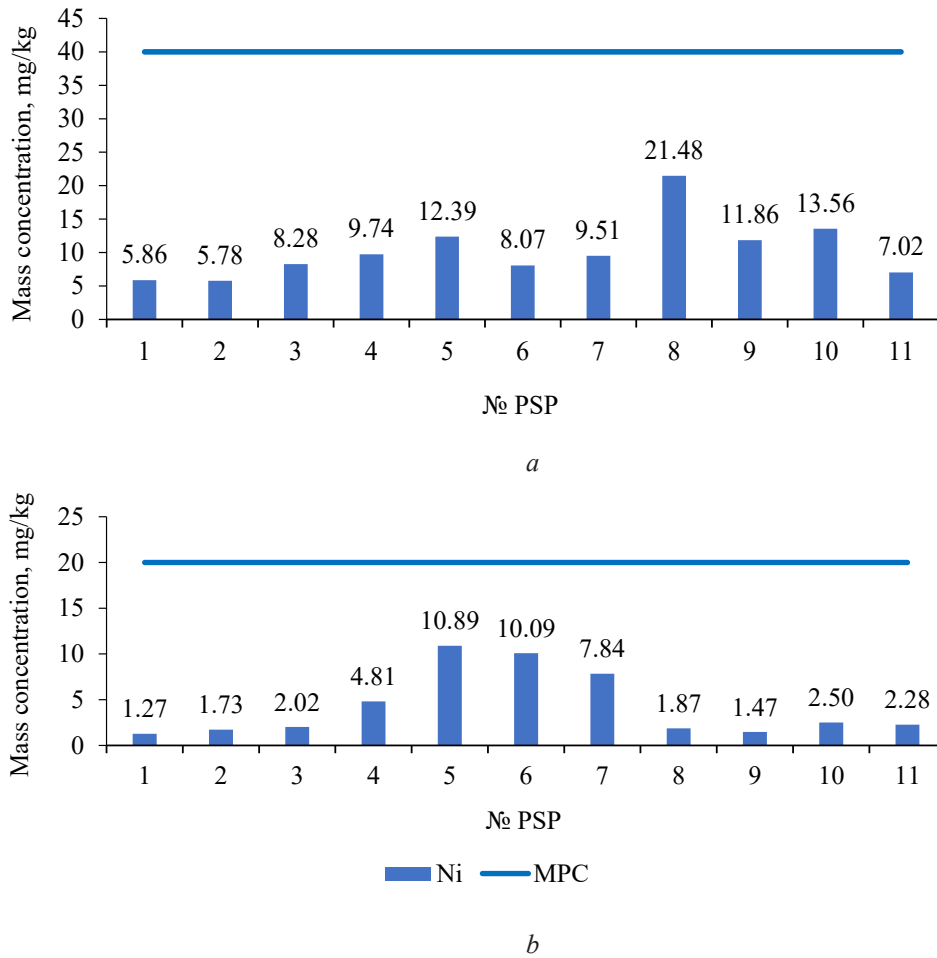


Fig. 4. The nickel content in the soil (a) and birch leaves (b)

At present, nickel in small concentrations is considered an essential microelement for plants, but its biological and agricultural value has been little studied [18]. To date, there is no data in the literature on the negative impact of nickel deficiency on plants, however, a number of experiments have revealed a positive effect of nickel application to soils on the yield of some agricultural crops [1, 15]. An excess of nickel in plants causes suppression of photosynthesis and transpiration processes, as well as the appearance of signs of leaf chlorosis, and deformation of plant organs [4, 6]. In the soil samples we have tested, the nickel content has turned out to be low (Fig. 4a). The maximum nickel concentrations in birch leaves (Fig. 4b) have been found in the sample plots in Kolomenskoye, which once again indicates a strong anthropogenic impact on the site. The BAC at PSP 7 is 1.25, which means that nickel is concentrated by birch in this area.

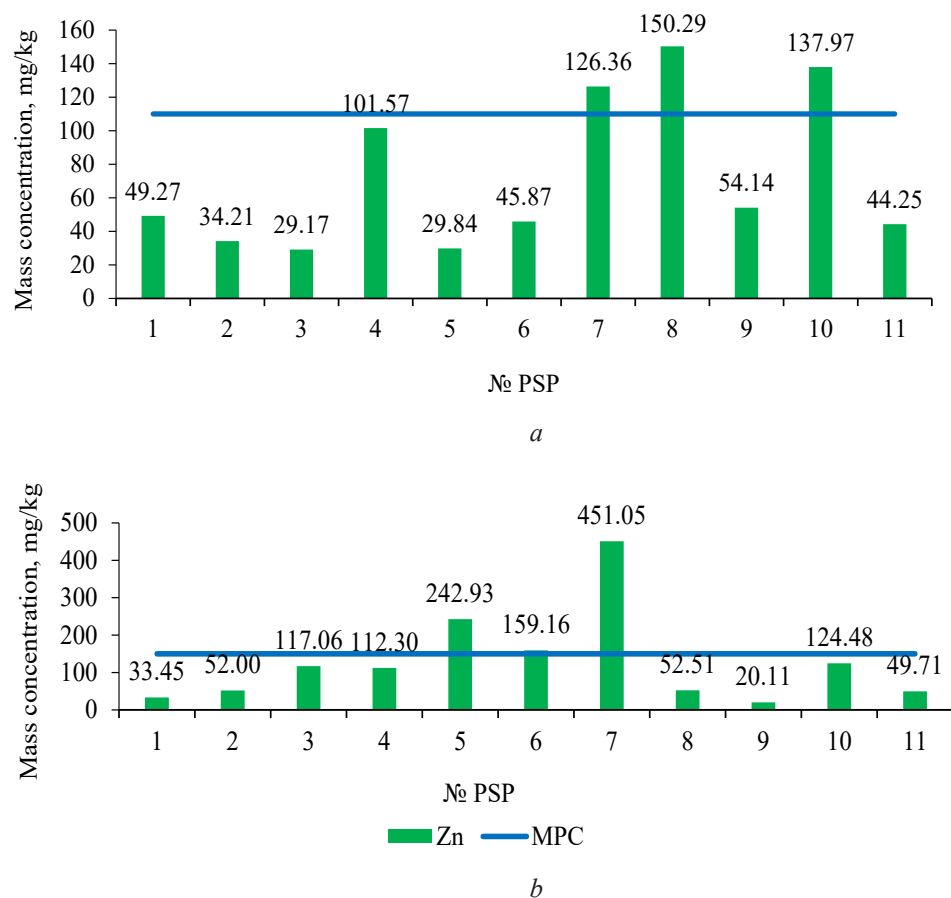


Fig. 5. The zinc content in the soil (a) and birch leaves (b)

Zinc is a toxic heavy metal, but unlike lead and cadmium, it is an important element for plant nutrition [2]. The physiological role of zinc is the activation of many enzymatic reactions. A high zinc concentration in the soil leads to slower growth and reduces fruiting of plants. Typical signs of zinc excess are leaf chlorosis and a slow plant growth. It has been established that the death of sensitive species of terrestrial plants can be observed at zinc concentrations in the soil of more than 100 mg/kg. Meanwhile, the symptoms of toxicity appear when this metal accumulates at concentrations of 100–300 mg/kg of dry weight, which depends on the plant species and genotype, as well as soil characteristics [16]. In the sample plots we have studied, excesses of the MPC of zinc in the soil have been found (Fig. 5a) in Kolomenskoye and in the MBG. Increased concentrations of zinc have also been found in birch leaves (Fig. 5b). Based on the data obtained, the BAC has been calculated, which has shown that birch trees at PSPs 2, 4, 10 and 11 exhibit concentration, and at PSPs 3, 5, 6 and 7 – overconcentration of zinc. The concentration of zinc in birch has been repeatedly noted by various researchers [8, 10, 11] and has been confirmed in our work.

Conclusion

Based on the results of the study of the soils and birch leaves in the Losiny Ostrov, the MBG and Kolomenskoye, a number of conclusions can be drawn regarding the ecological state of these natural objects. Concentrations of heavy metals in the soils of the studied plantations do not exceed the MPC level. The exception is zinc; its amount in some sample plots has been increased several times. However, it is the least toxic of all the heavy metals presented in the study.

The birch leaves have shown an uneven accumulation of heavy metals, depending on both the concentrations of elements in the soil and the location of the sample plots. In the leaves, the content of copper and cadmium is within the standards for all the sample plots laid.

It is significant that the excess of the MPC of lead in the leaves has been found in all the sample plots, which indicates a significant impact of technogenic facilities. The content of nickel in leaves does not exceed the MPC in any sample plot. Therefore, its impact on the environmental situation under these conditions is minimal.

The MPC of zinc in leaves is exceeded in Kolomenskoye. The data obtained has shown the need to continue studying the content of heavy metals in urban plantations experiencing a complex anthropogenic load.

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